Simulation of Wind-Induced Vortex Flow and the Effect on a Helicopter Structural Failure

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INTRODUCTION

Wind flow over topography is often converted to vortex flow due to the interaction of specific features of the terrain such as two mountain peaks. An example of this is found in the area of Straumsfjorden in Northern Norway at certain wind directions, see Figure 1. During an emergency flight along that coastline a rescue helicopter of type Eurocopter SA 365N Dolphin 2 experienced a sudden pitch-down change of attitude, which was subsequently corrected by the pilot and the automatic flight control system. After a safe landing the crew observed that both sides of the horizontal stabilizer was missing. Since the weather condition at the time of accident involved strong winds, the Norwegian Aircraft Accident Investigation Board ordered a numerical wind analysis of the mountainous area around the pitch-down location. The present paper reports on this study and also put forward a hypothesis of dynamic stall together with torsional loading as the cause for the mishap.

WIND SIMULATION ANALYSIS

The physical domain under study covers an area of 15 by 20 km and a height of 2 km. This domain was transformed to a numerical space based on a digital representation of the topography. Hence, about 400 000 computational cells were generated in which the non-viscous Euler equations for rotational flow were solved. The numerical method applied is based on the time stepping finite volume technique and incorporates cell-centered fluxes for spatial discretization. Time integration is performed by a three-stage Runge-Kutta method of second order accuracy. The Euler equations describes the conservation of mass and momentum for the velocity components u, v and w in a Cartesian coordinate system x, y and z. The variables are taken as the mean value within each computational cell. The solution is obtained by iteration and represents a steady state solution for the various flow fields, i.e. for each wind direction imposed.

The upwind velocity profile which serves as the input for the farfield is given as a power law with exponent alfa = 0.28. The velocity U inf represent the wind velocity

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at the height z ref = 400 m above the ground. The results from the numerical analysis show the dimensionless wind components U, V and W as

U = u (x,y,z) / U inf
V = v (x,y,z) / U inf
W = w (x,y,z) / U inf

Here positive values of U is in the direction of U inf whereas a positive value of V is to the right of that vector. Negative value of W means downward wind motion. Reference [1] presents computational results for wind directions from 140, 160, 180 (south), 200 and 220 degrees. Since wind from 200 degrees represent the most significant case for the vortex flow under discussion, that wind condition is used as the basis for the subsequent discussions, Figure 2.

FLIGHT PATH CONDITION

On May 17, 1999 a helicopter with registration code LN-OLT was flying over Straumsfjorden (south of Tromsø, Norway) in a westward direction. The flight altitude was 800 feet (= 244 m) and the speed was 150 knots (= 77 m/s). The wind was heavy (40-50 knots) and came from the South. At an estimated position of 69deg31min60s N and 18deg31min26s E the helicopter experienced a sudden pitch down movement. That position lies at the mouth of the river Brokskarselva, which again forms a canyon between the mountain peaks of Bentsjordtinden (1168 m above sea level) and Blåruttind (806 m), see again Figure 1. These peaks lies about 4500 m apart and are situated 2000-3000 m south of the flight path. Since the flight speed is known, a time axis along the flight path can be introduced and is shown in Figure 3. In addition we have defined the two locations of strong rotational flow from Figure 2, i.e. reference point A at Bentsjorda and point B at Brokskar.

The results from the simulated wind from 200 degrees and its effect along the flight path are shown in Figure 4 for three different flight altitudes. The wind components are now expressed with reference to the helicopter heading, i.e. with the dimensional relative velocities V head / U inf, V side / U inf and V vertical / U inf. As can be seen, strong variations are connected to the time points of t = –25 s (reference point A) and t = 55 s (reference point B). This is further illustrated in Figures 5 and 6 for the flight altitude of 800 feet and for three different wind speeds in the farfield. A combination of these results with the simulated head wind and the flight velocity will yield the change of angle of attack for the horizontal stabilizer (alfa) and the vertical fins (beta), see Figure 7 and 8 respectively.

STABILIZER LOADING

The static loading on the helicopter horizontal stabilizer, which is fitted with a trailing edge Gurney flap, will be estimated from data given in Reference [2]. Furthermore, due to a possible occurance of dynamic stall [3], the vertical loading on the stabilizer could exceed the design criteria. The basis for such a statement will be made clearer with reference to the time scale shown in Figures 7 and 8. A wind speed in the farfield in the order of 60 knots will also be assumed in the following discussion.

- Around the time point t = -25 s (reference point A) the horizontal stabilizer has experienced a change of incident in the order of +/- 5 degrees. This will yield a rapid vertical loading from upwards toward downwards within 30 s. Within the

same time period the left hand side vertical fin will feel a strong and fluctuating inward loading including stall. The result could be termed a torsional loading on the horizontal stabilizer, which could introduce buckling of the skin.

- Around the time point t = 55 s (reference point B) the helicopter undergoes a very strong decrease in side wind from the left hand side, but a weaker head wind (Figure 4). Since it is heading into a small vertical wind component, the stabilizer unit will experience a similar loading as at reference point A. The head wind has almost diminished at time t = 55 s, but the vertical wind component is at its peak and of the same magnitude as the side component. The fluctuations of the flow incident to the horizontal stabilizer is more rapid as compared to reference point A and, hence, it will yield a higher tendency of dynamic stall at the reduced frequency of k = 0.006 (T=40 s). However, it is more important to speculate on an initial rupture of the stabilizer skin at time reference t = -5 s, where we have a peak in headwind and downwind, with a following structural failure when entering reference point B.

A report issued by Eurocopter [4] says that the rupture of the stabilizer can be explained by aerodynamic calculations with a sudden entry into a vertical gust of 17.6 m/s, which is twice the value in the JAR29 Amendment 16 requirements. As shown in Figure 6, this value could well be exceeded for farfield winds of 80 knots. Furthermore, static failure tests have shown that a root moment of 5330 mN per half-stabilizer will also lead to a failure. If we assume a uniform loading over the stabilizer, this would yield (for t = -5 s) a vertical downward loading of 8460 N or a static lift coefficient corresponding to 2.1 for the specified flight conditions (with a head wind of 20 m/s) and given stabilizer geometry. Hence, a dynamic stall of the stabilizer at about t = -5 s can occur, partly due to rotor reaction of headwind.

As Figure 9 indicates, a 4% chord Gurney flap on a NACA 4412 airfoil would produce the trim value of 0.7 at -2 degrees angle of attack. Here we take the two-dimensional value as applicable also to our reference stabilizer. With a change in the angle of attack in the order of +4 degrees (see time reference point t = -5 s in Figure 7) the value for the lift coefficient will now read 1.2. This will lead to the static limit load due to trim (JAR 29.307a) of about 3030 N. Adding the possibility of stronger gusts and an influence of side wind (read vertical fins), the rupture of the stabilizer (see Figure 10) both due to a dynamic stall and a three-dimensional loading is at hand.

CONCLUSION

The primary conclusion from the present study is that the numerical simulation of steady-state wind conditions reveals strong vortex flow patterns in two areas of the flight path (Figure 11), with one coinciding with the location of the sudden nose-down movement of the subject helicopter (Figure 12) and also the recovery of the stabilizer in the fjord. This wind flow structure will further introduce strong transient flow conditions on the flight vehicle and on the horizontal stabilizer including the two vertical fins. This highly three-dimensional wind induced flow could be the cause for the structural failure of the stabilizer, however, no aerodynamic proof can be put forward.

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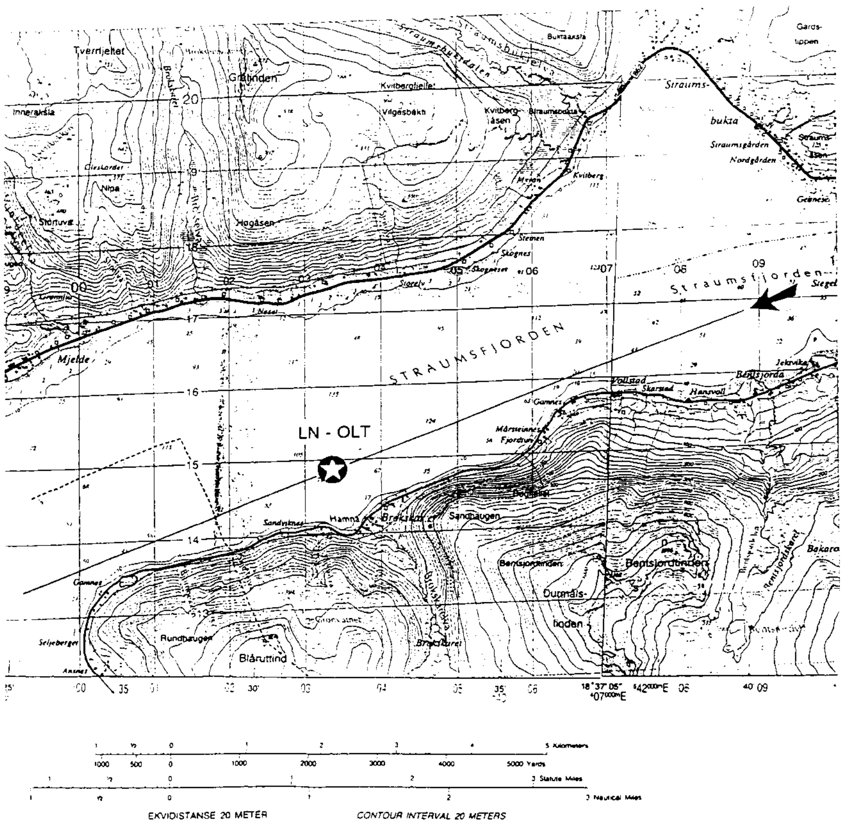

FIGURE 1 – Straumsfjorden and the surrounding topography

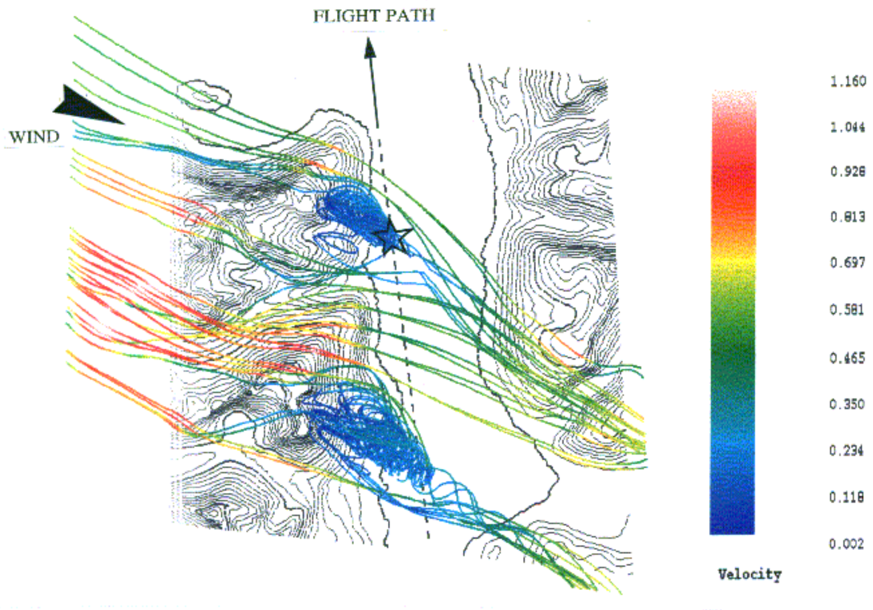

FIGURE 2 – Numerical wind simulation from 200 degrees

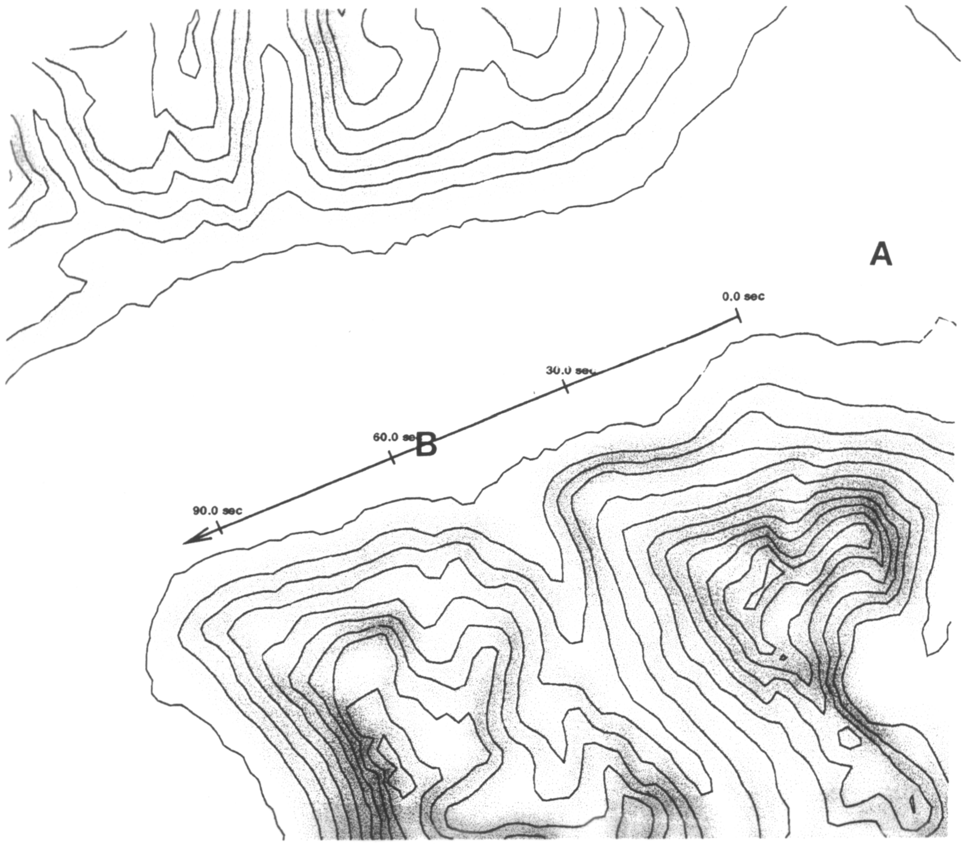

FIGURE 3 – Time axis along flight path and reference points A and B

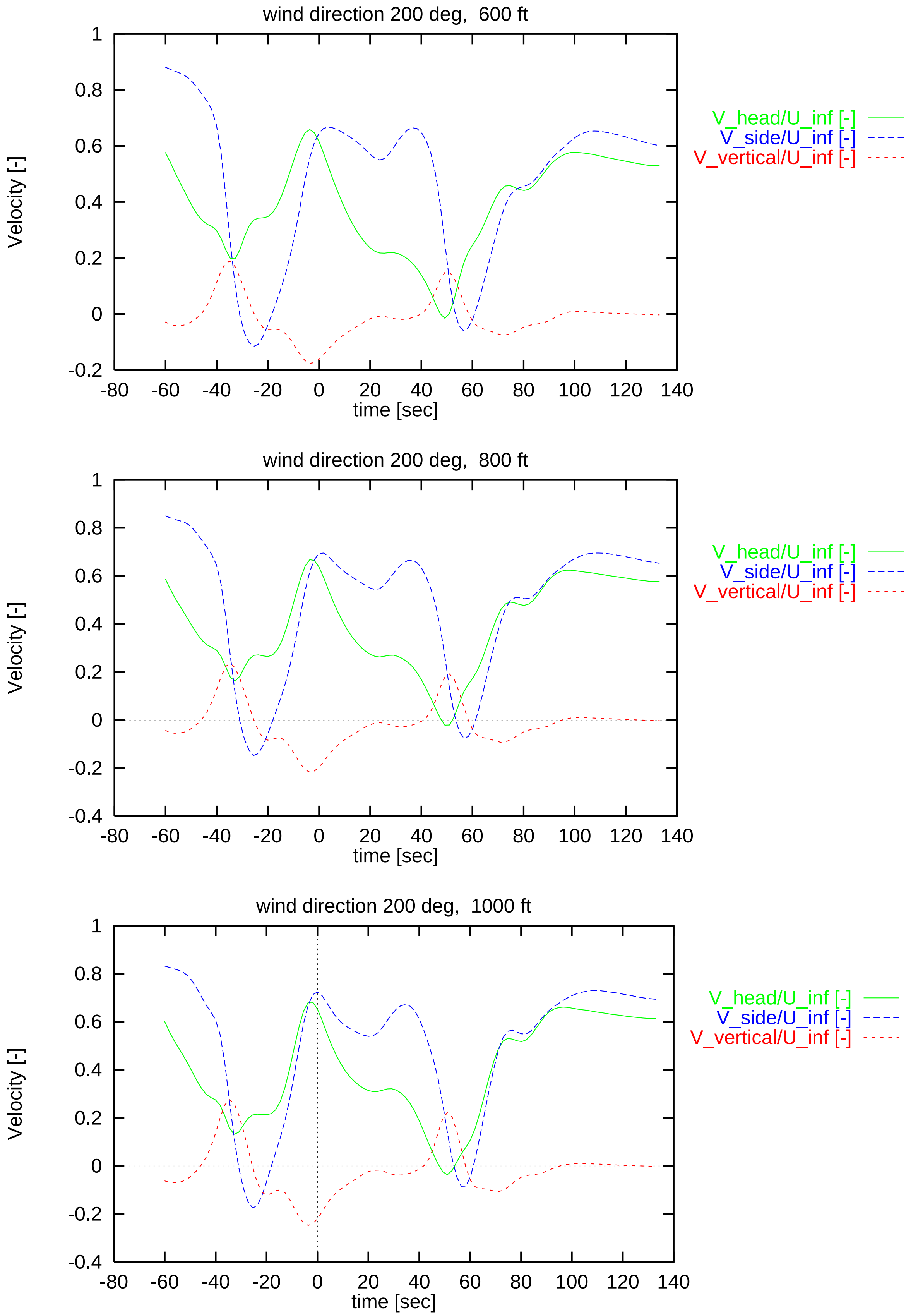

FIGURE 4 – Dimensionless wind components for various flight altitudes

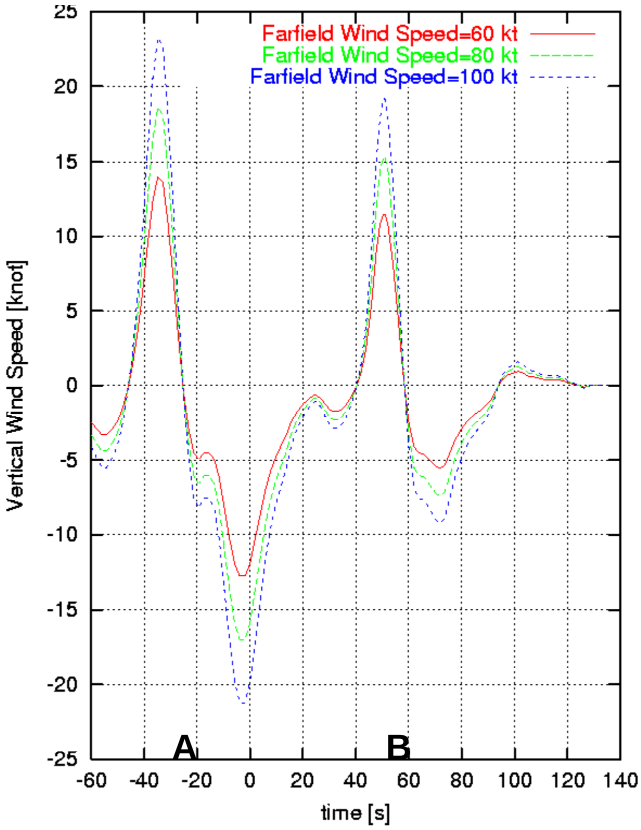

FIGURE 5 – Vertical wind component

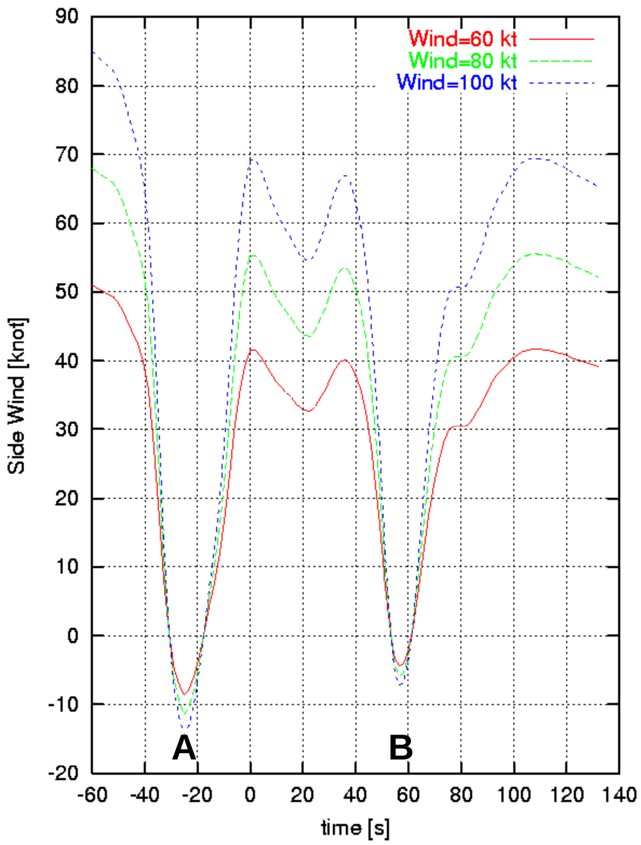

FIGURE 6 – Wind component from the side

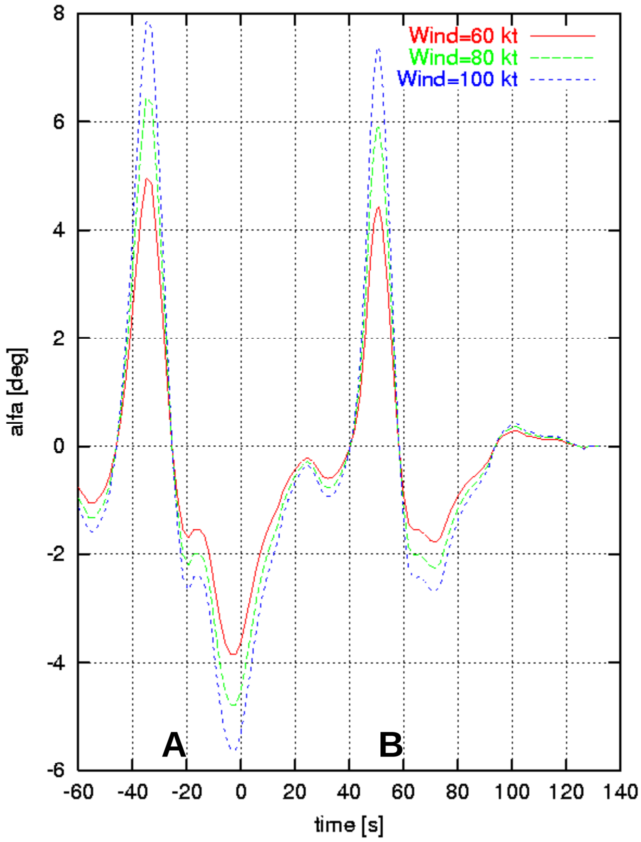

FIGURE 7 – Change of angle of attack (alfa) for the horizontal stabilizer

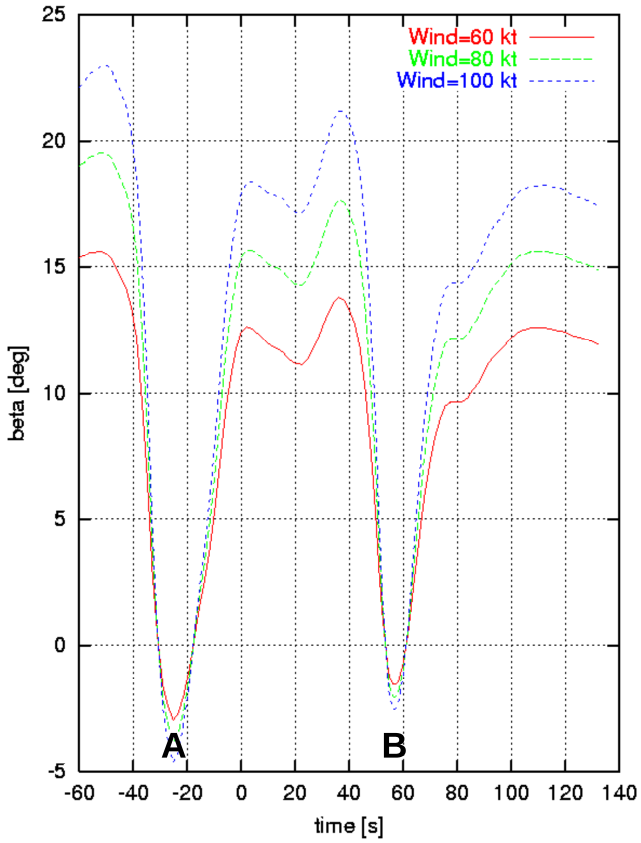

FIGURE 8 – Change of angle of attack (beta) for the vertical fins

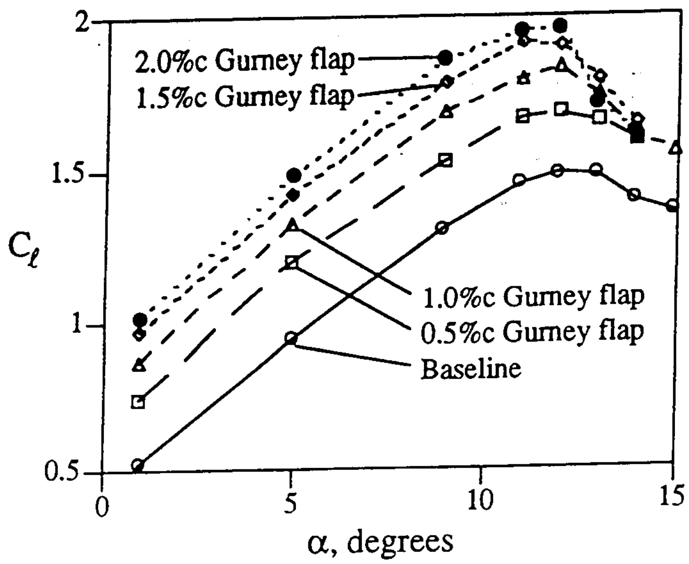

FIGURE 9 – Gurney flap aerodynamic data

The stabilizer (1) passes through the fin cone and is secured to it by 2 bolts (8). The leading edge and trailing edge spoilers (7) and (4) are screwed in. The outboard fins are secured to the outboard rib studs (6). A pocket (2) provides clearance for the position light (5) power supply wires to pass inside the tubes included in the stabilizer. A braid (3) ensures electrical bonding between the fin and stabilizer.

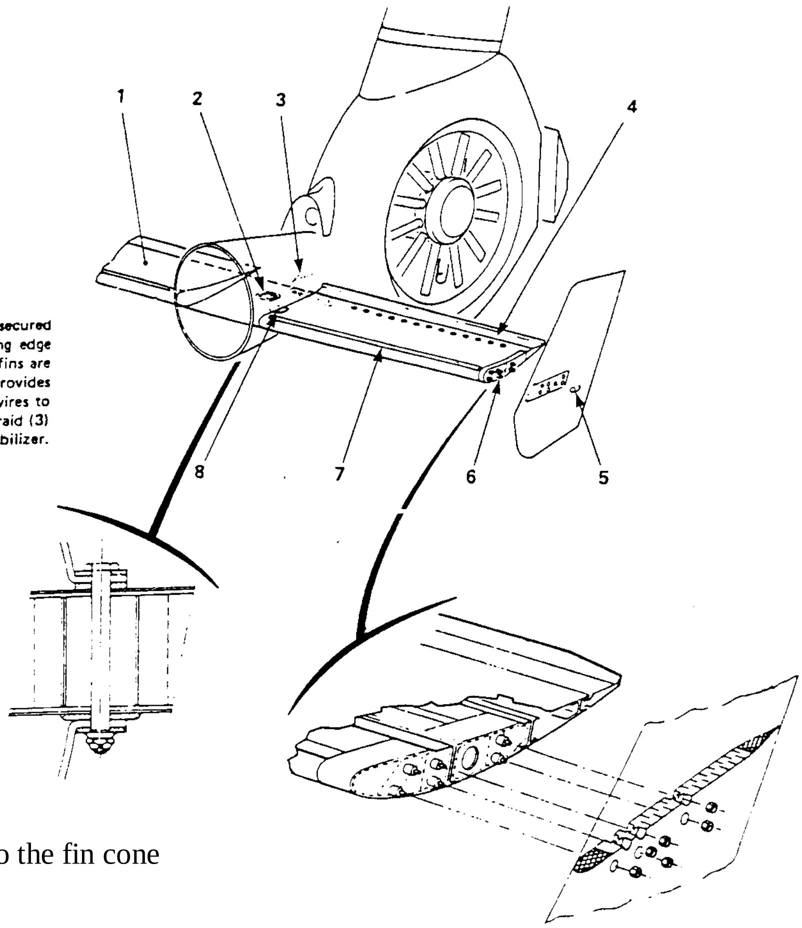

FIGURE 10 - Stabilizer mounting to the fin cone

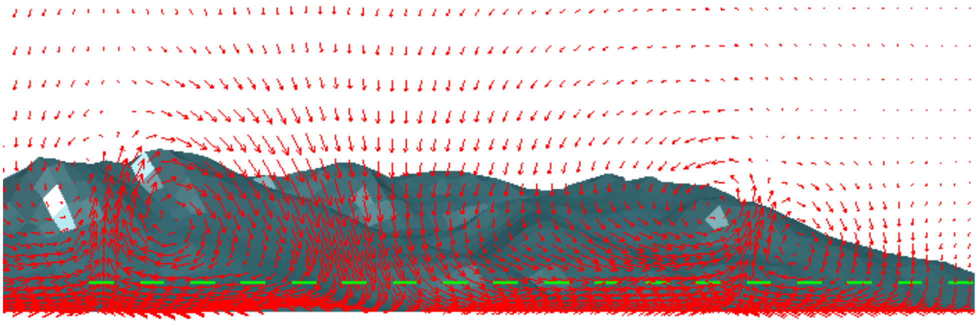

FIGURE 11 – Change of farfield wind velocity in flight plane due to topography

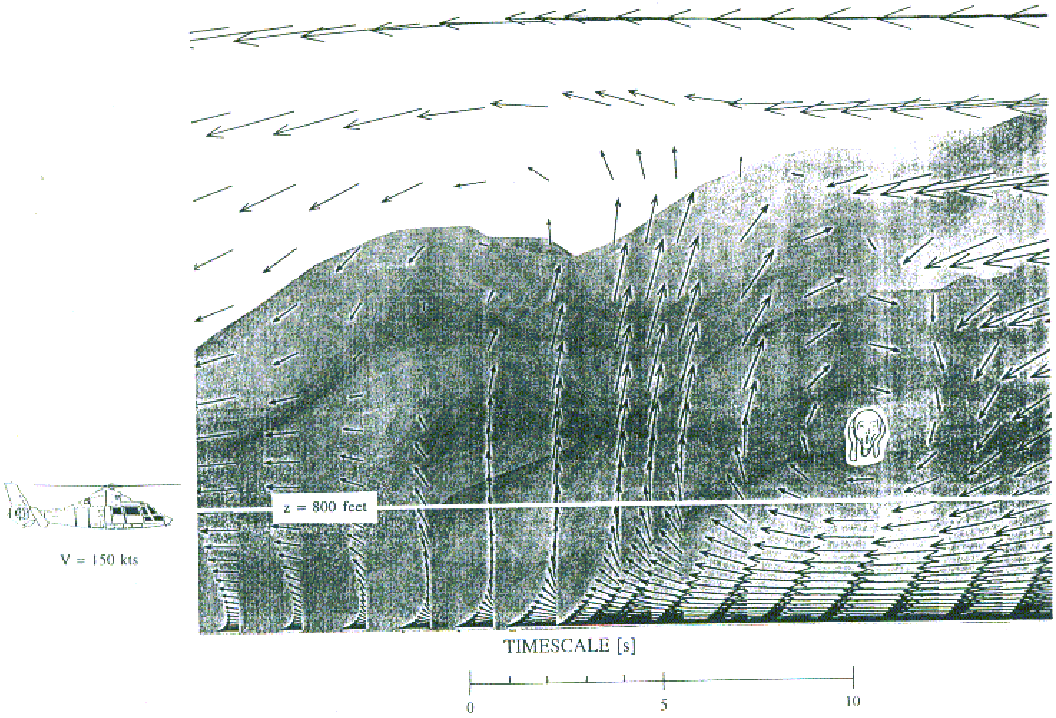

FIGURE 12 – Vector plot of wind velocity in the vertical plane along the flight path
(around reference point B)

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Question by Mr. Verhaagen: What is being done to avoid these incidents in the future? Have there been more incidents?

Answer: A total of three incidents have reportedly been filed for the subject helicopter. However, only the present incident is considered to be due to atmospheric turbulence. What can be done in the future is to inform the pilots of such damage when flying in similar mountainous areas under strong winds.

Question by Dr. Khalid: The helicopter surfaces are typically cleared against a variety of PSD spectra and even high intensity stepped gust loads. Can you confirm if the flight conditions exceeded the conditions against which the helicopter was actually cleared?

Answer: Without knowing all the flight regulations, aerodynamic calculations for the Eurocopter have confirmed that a rupture of the stabilizer can occur when entering a stepped vertical gust of 17.6 m/s. Our calculations have indicated that such flight conditions could have occurred.

Question by Mr. Templin: In consideration of the very complex flow encountered in atmospheric flow, can you comment on how an Euler code has been able to capture the key elements of the phenomenon without a simulation of viscous effects?

Answer: The oncoming wind in the far field is imposed with an atmospheric type boundary layer profile and, hence, is already rotational. The downstream effect from the topography, with large mountain peaks and river canyons, is captures by an Euler simulation as a first approximation. In our experience, a Navier-Stokes solution will not improve the situation if we also consider the cost aspect of the study goal.

Question by Mr. Cunningham: (Comment in support of Paper): The F-16 has had three incidents of loss of the top 1/3 of the vertical tail when chasing and F-15 in dogfight exercise. The loss was attributed to a very precise encounter on the F-15 wing tip vortex that has a small probability of occurrence and is not designed for. Three occurrences within several million hours of flight time for F-16's worldwide is indicative of the rarity of occurrence. Your assessment seems very reasonable.

Answer: Thank you very much for your support.

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